ADVANCED CONCEPTS

A Survey of Hypersonic Shock Tunnel Facilities Employing Heated Driver Gases

R. F. Sturgeon

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ADVANCED CONCEPTS DEPARTMENT
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FOREWORD

This survey was performed in support of Contract NAS 8-11,078, between the National Aeronautics and Space Administration and the Lockheed-Georgia Company. Detailed results of the study conducted under this contract are described in Lockheed-Georgia Company Engineering Report, ER 6677, Shock Tube Driver Gas Heating Techniques - Final Report, dated 29 January 1964.

The work at the Lockheed-Georgia Company under this contract was the responsibility of the Advanced Concepts Department, R. H. Lange, Manager, with R. F. Sturgeon serving as Project Leader.

Contributions of the aerospace companies and government agencies to the Survey are hereby acknowledged, with appreciation.

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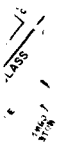

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ABSTRACT

This report presents a compilation of the data received in response to questionnaires submitted to appropriate companies and agencies in a survey of the extent to which the several methods of driver gas heating are used in hypersonic shock tunnel facilities. A listing of the participants who contributed to the survey is included. Descriptions of facilities employing heated driver gases in hypersonic shock tunnels, which are grouped with respect to the heating method used, are given.

AUTHOR

THE SURVEY

Introduction

This report presents the results of a survey conducted to determine the number and nature of operational and planned hypersonic shock tunnel facilities that employ heated driver gases. The information is based on data received from 15 companies, agencies, or institutions that responded to a questionnaire mailed to them in July of 1963.

Companies Responding

Arnold Engineering Development Center
Arnold Air Force Station, Tennessee

Cornell Aeronautical Laboratory, Inc.
4455 Genesee Street
Buffalo 21, New York

Douglas Aircraft Company, Inc.
3000 Ocean Park Boulevard
Santa Monica, California

General Applied Science Laboratories, Inc.
Merrick and Stewart Avenues
Westburg, L. I., New York

General Dynamics/Convair
P. O. Box 1950
San Diego 12, California

Grumman Aircraft Engineering Corporation
So. Oyster Bay Road
Bethpage, L. I., New York

Lockheed-California Company
P. O. Box 551
Burbank, California

Lockheed Missiles and Space Company
3251 Hanover Street
Palo Alto, California

Martin Marietta Corporation
Space Systems Division
Baltimore 3, Maryland

NASA Ames Research Center
Moffett Field, California

NASA Langley Research Center
Langley Station
Hampton, Virginia

U. S. Naval Ordnance Laboratory
White Oak
Silver Spring, Maryland

Northrup Corporation, Norair Division
1001 East Broadway
Hawthorne, California

Polytechnic Institute of Brooklyn
Bedford Avenue and Avenue H
Brooklyn, New York

Rensselaer Polytechnic Institute
Troy, New York

The Questionnaire Letter

Accompanying each questionnaire was a letter explaining that the Lockheed-Georgia Company was engaged in NASA study Contract NAS 8-11,078 which required a knowledge of the operating characteristics of existing and planned hypersonic shock tunnels with particular interest in those employing heated driver gases.

The Questionnaire

The questionnaire, which was spaced over seven pages to allow ample room for answers, asked the following questions:

1. Designation of Facility
2. Operational Date
3. Test Section Size
4. Driver Tube
   a) Length
   b) Inside Diameter
   c) Outside Diameter
   d) Maximum Pressure
5. Driven Tube
   a) Length
   b) Inside Diameter
   c) Outside Diameter
   d) Maximum Pressure
6. Shock Mach Number Range
7. Reservoir Temperature Range
8. Reservoir Pressure Range
9. Length of Test Run
10. Is the Shock Tube Operated under Tailored Conditions
11. Driver Gases Used
12. Is a Gas Reclamation System Used

13. Method of Heating Driver Gas

a) None

b) Arc Heating

1) Energy capacity and voltage

2) Temperature range of driver gas

3) Cycle time

4) Operational difficulties

c) Combustion Heating

1) Pressure range before combustion

2) Pressure range after combustion

3) Temperature range of driver gas

4) Cycle time

5) Method of igniting mixture

6) Operational difficulties

d) Plasma Jet Heating

1) Power input

2) Temperature range of driver gas

3) Time from ambient to maximum temperature

4) Operational difficulties

e) Internal Electrical Resistance

1) Type of heating element

2) Approximate life of heating element

3) Power input

4) Temperature range of driver gas

5) Time from ambient to maximum temperature

6) Operational difficulties

f) External Electrical Resistance

1) Type of heating element

2) Power input

3) Temperature range of driver gas

4) Time from ambient to maximum temperature

5) Operational difficulties

g) Buffered Heating

1) Gases used

2) Pressures used

3) Temperature range of driver gas

4) Cycle time

5) Operational difficulties

h) Other

14. Approximate Cost of Complete Facility

15. Approximate Cost of Heater Installation

16. Remarks and Additional Explanation

Shock Tunnel Facilities Summary

In the tables on the two following pages, data describing heated shock tunnel facilities are grouped according to the method utilized to heat the driver gas.

Information is presented in the general form submitted by the participants. A deficiency of data is noticeable in some entries since all of the questions on some of the questionnaires were not answered by the responding

organizations. Operational and planned operational dates are given by year only. The planned operational dates, however, may vary somewhat.

The survey is not complete since some companies and agencies either declined to answer the survey questions or were inadvertently omitted from the mailing list.

NO.	FACILITY	OPERATIONAL DATE	TEST SECTION DIAMETER (IN.)	DRIVER TUBE			DRIVEN TUBE			SHOCK MACH NUMBER	MAXIMUM DRIVER GAS TEMPERATURE (°F)	ENERGY STORAGE (joules)	DRIVER GASES	TEST TIME (MSEC)	TAILORED OPERATION	REMARKS
				LENGTH (FT.)	I.D. (IN.)	PRESSURE (PSI)	LENGTH (FT.)	I.D. (IN.)	PRESSURE (PSI)							
1	ARNOLD ENGINEERING DEVELOPMENT CENTER MODIFIED EXPANSION TUBE	NOT OPERATIONAL	6.75	11 IN.	2.87	25,000	6.8	1.6	25,000	—	—	10^6 4000 V.	He	—	NO	UNDER DEVELOPMENT
2	LANGLEY RESEARCH CENTER (NASA) RE-ENTRY PHYSICS SHOCK TUNNEL	1960	36	14	3.76	25,000	72	3.8	3,500	—	—	2.5×10^6 12000 V.	He	1-5	NO	UNDER DEVELOPMENT

Table I Arc Heated Facilities

NO.	FACILITY	OPERATIONAL DATE	TEST SECTION DIAMETER (IN.)	DRIVER TUBE			DRIVEN TUBE			SHOCK MACH NUMBER	MAXIMUM DRIVER GAS TEMPERATURE (°F)	POWER INPUT (KW)	DRIVER GASES	TEST TIME (MSEC)	TAILORED OPERATION	REMARKS
				LENGTH (FT.)	I.D. (IN.)	PRESSURE (PSI)	LENGTH (FT.)	I.D. (IN.)	PRESSURE (PSI)							
1	CORNELL AERONAUTICAL LABORATORY, INC. 48" HYPERSONIC SHOCK TUNNEL	1959	48	20	8	6,000	60	8	15,000	1.5-5.5	1000	50	AIR He	4-20	YES	
2	LOCKHEED MISSILES AND SPACE CO. HYPERSONIC SHOCK TUNNEL	1960	6	9	3	10,000	30-40	3	10,000	—	740	0.5	H_2 He	—	YES	COMBUSTION HEATING ALSO USED.
3	MARTIN SPACE SYSTEMS HYPERSONIC SHOCK TUNNEL	1965	72	15	6.5	30,000	45-79	4	30,000	3-18	750	—	H_2 He	1-5	YES	PLANNED

Table II External Resistance Heated Facilities

NO.	FACILITY	OPERATIONAL DATE	TEST SECTION DIAMETER (IN.)	DRIVER TUBE			DRIVEN TUBE			SHOCK MACH NUMBER	MAXIMUM DRIVER GAS TEMPERATURE (°F)	POWER INPUT (KW)	DRIVER GASES	TEST TIME (MSEC)	TAILORED OPERATION	REMARKS
				LENGTH (FT.)	I.D. (IN.)	PRESSURE (PSI)	LENGTH (FT.)	I.D. (IN.)	PRESSURE (PSI)							
1	ARNOLD ENGINEERING DEVELOPMENT CENTER MODIFIED EXPANSION TUBE	1963	6.75	11 IN.	2.87	25,000	6.8	1.6	25,000	—	—	—	He	0.1-0.3	—	USED FOR DEVELOPMENT; NOT A PRODUCTION FACILITY.
2	LOCKHEED-CALIFORNIA COMPANY HYPERVELOCITY PILOT TUNNEL	1962	18	8	4	3,000	26	3	3,000	10-20	1500	200	AIR He N_2	0.5-0.5	NO	
3	LOCKHEED-CALIFORNIA COMPANY 100" HYPERVELOCITY TUNNEL	1964	100	10	6	45,000	28-40	6	45,000	TO 25	2000	1200	AIR He A N_2 H_2	5	NO	PLANNED
4	NORTHROP NORAIR HYPERSONIC SHOCK TUNNEL	1965	72	25	12	100,000	50	6	100,000	4-9.8	650	1000	H_2 He N_2	2-12	YES	PLANNED

Table III Internal Resistance Heated Facilities

NO.	FACILITY	OPERATIONAL DATE	TEST SECTION DIAMETER (IN.)	DRIVER TUBE			DRIVEN TUBE			SHOCK MACH NUMBER	MAXIMUM DRIVER GAS TEMPERATURE (^{o}F)	DRIVER GASES	TEST TIME (MSEC)	TAILORED OPERATION	REMARKS
				LENGTH (FT.)	I.D. (IN.)	PRESSURE (PSI)	LENGTH (FT.)	I.D. (IN.)	PRESSURE (PSI)						
1	DOUGLAS AEROPHYSICS LABORATORY HYPERVELOCITY IMPULSE TUNNEL	1963	30	34	6	30,000	31	5	30,000	2.5-12	4500	H_2 He O_2 N_2	10-25	YES	
2	GENERAL APPLIED SCIENCE LABORATORY TUNNEL NO. 1	1963	42	24	6	30,000	28	3	30,000	8.2	3500	AIR N_2 H_2 O_2 He	5-20	YES	
3	GENERAL DYNAMICS-CONVAIR HYPERSONIC LABORATORY	1962	36	5	5	100,000	48	2	100,000	2-12	—	H_2 He O_2	5-15	YES	
4	GRUMMAN HYPERSONIC SHOCK TUNNEL	1959	20 X 20	20	5	100,000	100	3	100,000	2-8	3500	H_2 He O_2	1-4	NO	TAILORED OPERATION WITH SHORTER DRIVEN TUBE
5	AMES RESEARCH CENTER (NASA) PROTOTYPE HYPERSONIC FREE-FLIGHT FACILITY	1961	24	40	6.25	50,000	40	6.25	20,000	TO 9.5	3700	H_2 He O_2	TO 10	YES	
6	AMES RESEARCH CENTER (NASA) 1-FOOT SHOCK TUNNEL	1962	12 X 12	24	27	5,600	40	6.2	9,000	9-19	3400	H_2 He O_2	4-6	YES	UP TO 180 MSEC TEST TIME UNDER "TOTAL EQUILIBRIUM" INTERFACE OPERATION.
7	LANGLEY RESEARCH CENTER (NASA) RE-ENTRY PHYSICS SHOCK TUNNEL	1960	36	14	3.76	25,000	72	3.8	3,500	—	—	H_2 He O_2	1-5	NO	ARC HEATING ALSO USED.
8	LOCKHEED MISSILES AND SPACE CO. HYPERSONIC SHOCK TUNNEL	1960	6	9	3	10,000	30-40	5	10,000	1.15-22	—	H_2 He O_2	.01-1	YES	EXTERNAL RESISTANCE HEATING ALSO USED.
9	POLYTECHNIC INSTITUTE OF BROOKLYN	1962	72	24	6	30,000	28	3	30,000	6-15	—	H_2 He O_2	TO 10	YES	
10	RENSSELAER POLYTECHNIC INSTITUTE LOW DENSITY HYPERSONIC SHOCK TUNNEL	1961	12-24	10	3	100,000	52	2	40,000	1.15-20	—	H_2 He O_2	TO 4	YES	
11	U.S. NAVAL ORDNANCE LABORATORY HYPERSONIC SHOCK TUNNEL NO. 1	1959	4-10	6.6	3.75	55,000	25	1.5	35,000	4-15	4300	H_2 He O_2	0.4-1.2	NO	
12	U.S. NAVAL ORDNANCE LABORATORY HYPERSONIC SHOCK TUNNEL NO. 2	1959	6	3.3	3.75	55,000	25	1.5	35,000	8-18	4300	H_2 He O_2	TO 1.7	YES	
13	U.S. NAVAL ORDANCE LABORATORY HYPERSONIC SHOCK TUNNEL NO. 3	1959	20	12	10	40,000	61	4	35,000	6-10	5400	H_2 He O_2	3-4	YES	

Table IV Combustion Heated Facilities